Chapter 3 Livestock system for milk production and trade: An analysis of economic and zootechnical indicators for food security and sustainability

Capítulo 3 Sistema ganadero para la producción y comercio de leche: Un análisis de indicadores económicos y zootécnicos para la seguridad alimentaria y la sustentabilidad

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Abstract

The objective of this paper is to examine the livestock system regarding the production and trade of milk, through overall management of the national and international market to an analysis of the main economic and zootechnical indicators, in order to understand how these, affect the permanence of Mexican companies in the livestock sub-sector of cow's milk production. Thus, an updated bibliographic synthesis on the production and trade of milk, to know the commercial context in which companies compete with each other, was carried out. This paper also contributes to information on the production and reproduction parameters of dairy cattle, good feeding, and housing management practices of dairy animals. This information will support any person who is engaged in, or has a relationship with, the sustainable production of dairy cows.

Livestock system, Production and reproduction parameters, Good feeding, management practices of dairy animals

Resumen

El objetivo de este capítulo fue caracterizar el sistema ganadero para la producción y comercialización de leche, a través del manejo integral del mercado nacional e internacional y un análisis de los principales indicadores económicos y zootécnicos, para comprender cómo éstos afectan la permanencia de las empresas mexicanas, en el subsector ganadero de la producción de leche de vaca. En este sentido, se realizó una síntesis bibliográfica actualizada sobre la producción y comercialización de leche, para conocer el contexto comercial en el que las empresas compiten entre sí. El capítulo también aporta información sobre los parámetros productivos y reproductivos del ganado lechero y buenas prácticas de alimentación y manejo de instalaciones para animales lecheros. Información que servirá de apoyo a toda persona que se dedique o tenga relación con la producción sustentable de vacas lecheras.

Sistema ganadero, Parámetros productivos y reproductivos, Buenas prácticas de alimentación, Manejo de animales lecheros

Introduction

In 2013, the World Organization for Animal Health (2014) defined a Dairy Production Unit as a commercial livestock production system which purpose involves the breeding, reproduction, and management of livestock for milk production. Furthermore, the Food and Agriculture Organization of the United Nations (2021b), together with the Organization for Economic Co-operation and Development (2020), indicate that in different territories of the world it has been noted that, between large and small Dairy Production Units, there are productivity gaps, understood as the differences between milk production per cow in the herd, per hectare, per wage, or per year.

These productivity gaps reflect the integrated management of anthropological factors, land and animal components, physical factors, feeding, health, milking, reproduction, and livestock management sub-systems (Luik-Lindsaar *et al.*, 2019). The integration of these zootechnical and economic indicators leads to establishment and profit-making (Gaworski *et al.*, 2018), quantifying the exchange relations between the Dairy Production Unit and the market and reflecting the balance between investments, such as direct and indirect labor and livestock inputs (Bokusheva and Čechura, 2017). However, different cow milk production systems present particular problems of productivity, competitiveness, and sustainability, each associated with their own characteristics, regions, and management. Thus, in order to maintain or increase the productivity of cattle herds, it is imperative to characterize and integrate these zootechnical and economic indicators as a viable and practical proposal that allows farmers to participate successfully in national production (Bewley *et al.*, 2017).

This paper reviews: i) International production and trade of milk and dairy products; ii) Domestic production and trade of milk and dairy products; iii) Productive and reproductive parameters of dairy cattle; iv) Good feeding practices for dairy cattle; and v) Good management practices for dairy animal facilities. This information will support anyone involved in, or related to, sustainable development in intensive dairy cattle production.

References for acronyms and abbreviations

AI	Artificial Insemination at Fixed Time
AU	Animal Unit, 450 kg Bovine Equivalent
BI	*Bos indicus*
BT	*Bos taurus*
CH_4	Methane
CP	Crude Protein
D	Day
DM	Dry Matter
DPU	Dairy Production Unit
FAO	Food and Agriculture Organization of the United Nations
FIRA	Fideicomisos Instituidos en Relación con la Agricultura
ha/AU/year	Hectares per Animal Unit per Year
kg	Kilogram
L	Liter
LW	Live Weight
mL	Milliliter
mov/min	Movements per Minute
NPN	Non-Protein Nitrogen
OCDE	Organization for Economic Cooperation and Development
Odepa	Oficina de Estudios y Políticas Agrarias
pH	Potential of Hydrogen
PWM	Powdered Whole Milk
rep/min	Repetitions per Minute
SC	Somatic Cells
SCC/mL	Somatic Cell Content per Milliliter
SENASICA	National Service for Agri-food Health, Safety, and Quality
SMP	Skim Milk Powder
t	Ton
t, milk eq.	Tons of Milk Equivalent
U.S.	United States of America
USD	United States Dollar
USDA	United States Department of Agriculture
ZVD	Zootechnician Veterinary Doctor

1. Production and international trade of milk and dairy products

Despite market movements related to the SARS-CoV-2 Coronavirus pandemic, during 2020, world milk production increased 1.4% over last year (Food and Agriculture Organization of the United Nations, 2021b), reaching 860 million t of milk equivalent (Table 3.1), with a global *per capita* human consumption of 111.4 kg/year – i.e., an increase of 0.3% over 2019 (Food and Agriculture Organization of the United Nations, 2021a).

Table 3.1 International Milk Production Market 2018-2020 Period, Million Tons of Milk Equivalent

	2018	Years 2019	2020	Change from 2019 to 2020
	million t. milk eq.[a]			%
World Balance				
Total Production	840.3	848.0	860.1	1.4
Total Trade	76.0	76.8	77.9	1.5
Human Consumption *per capita*				
World (kg/year)	111.3	111.2	111.4	0.3
Trade. Share of Production (%)	9.0	9.1	9.1	0.0

[a] milk equivalent: the weighted average, calculated on a milk fat basis and a nonfat milk solids basis, with conversion factors equivalent to:

- 1,000 mL. * 11.8% total solids for whole milk
- 1,000 mL. * 8.5% nonfat solids for skim milk
- 1,000 mL. * 6.5% milk solids for whey
- 1,000 mL. * 3.5% milk solids for cream

Source of reference: Based on (Food and Agriculture Organization of the United Nations, 2021a)

Increases were seen in major milk producing countries (e.g., India) where management is sustained by monsoons and the resilience of its network of village cooperatives (Vivek *et al.*, 2020), or in the European Union and the United States (**U.S.**), which are supported by their yield improvements and government assistance, maintained stable economic margins for producers (Kutkowska *et al.*, 2020).

In this context, due to biological and cultural diversity, the milk consumed by humans comes from different species (Table 3.2) (Domínguez-Salas *et al.*, 2019) and the key elements that determine its maintenance are feed, water, and climate (Osei-Amponsah *et al.*, 2020).

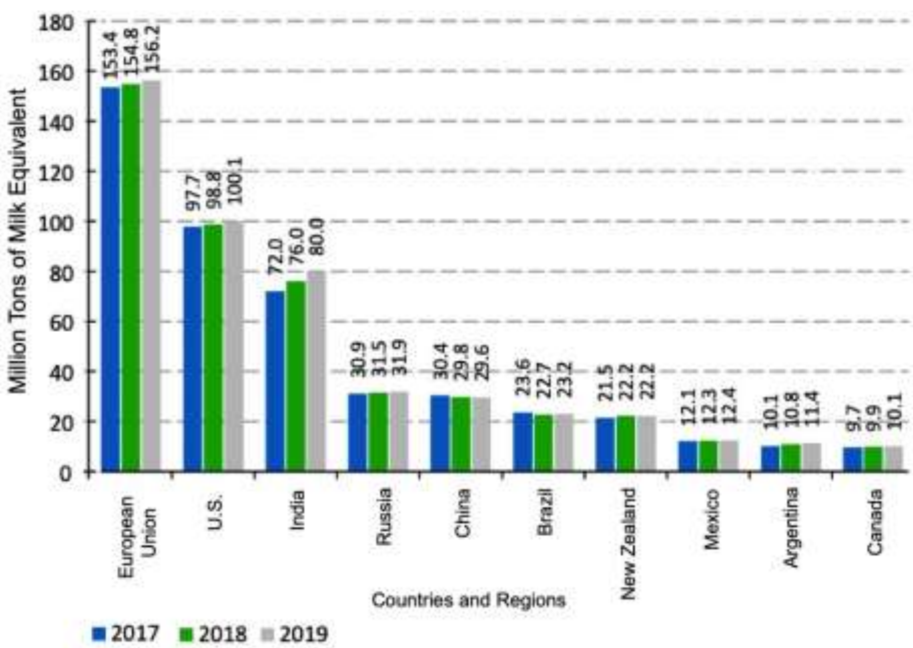
Table 3.2 International Milk Production by Species, Year 2020, Million Tons of Milk Equivalent

Species	Volume Produced	Percentage
	million t. milk eq.	%
Bovine	696.6	81
Bubalino	129.0	15
Goats	17.2	2
Sheep	8.6	1
Other	8.6	1
Total	860	100

Source of reference: Based on (Food and Agriculture Organization of the United Nations, 2021b)

Among such species, cattle (e.g., Holstein, Jersey, and Brown Swiss) stand out, with an average annual growth of 0.9%, and an estimated inventory of 141.7 million head, with which 81% of the world's milk production is achieved (Fideicomisos Instituidos en Relación con la Agricultura, 2019). This is followed by Bubalino (e.g., Murrah, Nili-Ravi, Surti, and Mehsana) with 15%; Goats (e.g., French Alpine, Saanen, and Toggenburg) with 2%; Sheep (e.g., Manchega, Churra, Hidango, and East Friesan) with 1%; and the remaining share comes from other dairy species (e.g., Yaks) (Food and Agriculture Organization of the United Nations, 2021b). The United States Department of Agriculture (2021) reported production of 156.2 million t of milk equivalent, 23.2 million head, and a share of 30.6%. The European Union stood out in 2019 as the main bovine milk producing region (Figure 3.1), with Germany acting as main producer with 20% and a dairy herd that exceeded 4 million head, followed by France with 15%. In third position was the United Kingdom with 10%.

Figure 3.1 Major Producers of Cow's Milk in the World During the Period 2017-2019, Million Tons of Milk Equivalent

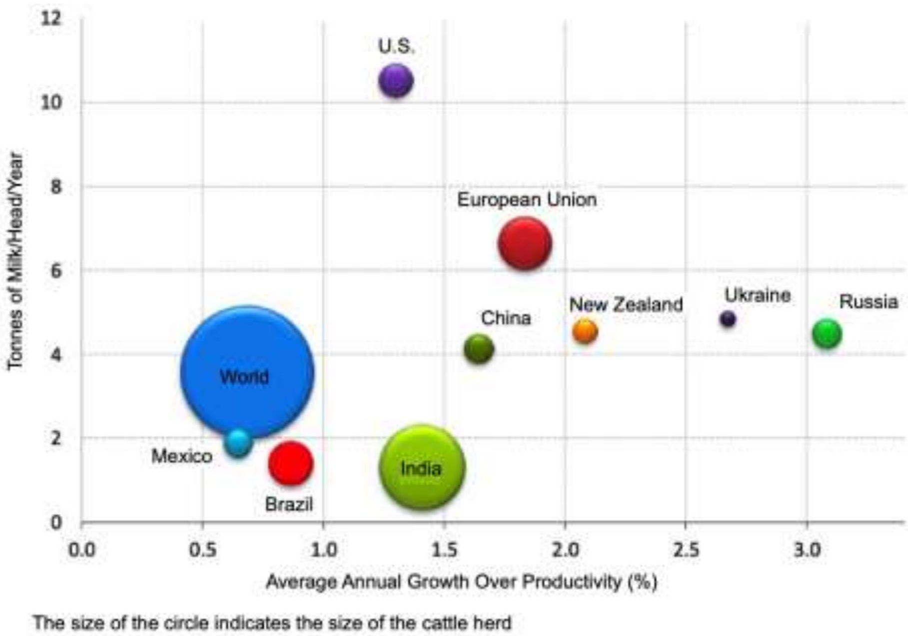


Source of reference: (United States Department of Agriculture, 2021)

With an estimated 9.3 million head count, the highest productivity among countries (10.5 t of bovine milk/head/year), and with 100.1 million t of milk equivalent, the U.S. (Figure 3.2) is the second largest producer of bovine milk during 2019. California, Wisconsin, Idaho, New York, and Pennsylvania are the five U.S. states that account for 50% of the country's production (Fideicomisos Instituidos en Relación con la Agricultura, 2021). In India, milk production during 2019 represented 27.9% of the world's milk supply, with 80.0 million t of bovine milk equivalent, an estimated inventory of 58.5 million head (Kutkowska *et al.*, 2020), and the lowest productivity among countries (1.3 t of bovine milk/head/year) (Domínguez-Salas *et al.*, 2019).

However, it is appropriate to note that the bubalino population represents its main source of production (Vivek *et al.*, 2020). So much so that when considering the combined production of cows and buffaloes, India would rank as the largest milk producer in the world (Organization for Economic Cooperation and Development, 2020).

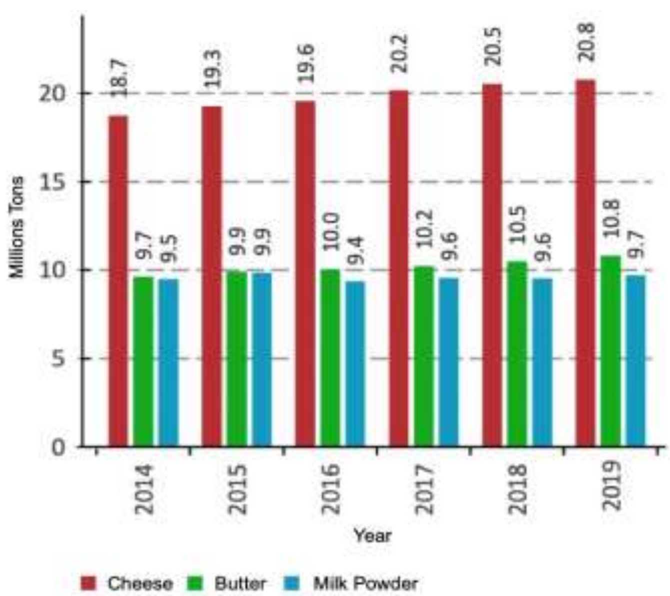
Figure 3.2 Dairy Herd and Global Productivity in Milk Producing Countries, Year 2019



Source of reference: (United States Department of Agriculture, 2021)

Regarding its distribution during 2019, industrial consumption accounted for 70% of the world's total, while human consumption used 29.2%, and animal consumption used the remaining 0.8% (Kutkowska *et al.*, 2020). Furthermore, the Organization for Economic Cooperation and Development (2020) noted that, during 2018, the U.S., accounted for 16.3% of the world's consumption. It should be remembered that in the U.S., 77% of total milk consumption is used for the production of cheese, butter, and in the powdered milk processing industry (United States Department of Agriculture, 2021). The Food and Agriculture Organization of the United Nations (2021a) indicated that during 2019, the international production of dairy derivatives reached 41.3 million t. Cheese was the product with the highest volume produced, with 20.8 million t, equivalent to 50.6% of the total (Figure 3.3); butter accounted for 25.8%; and powdered whole milk (PWM) and skim milk powder (SMP) combined for 9.7 million t, equivalent to 23.5% of the total (Fideicomisos Instituidos en Relación con la Agricultura, 2019).

Figure 3.3 International Production of Main Dairy Derivatives, 2014-2019 Period, Million Tons

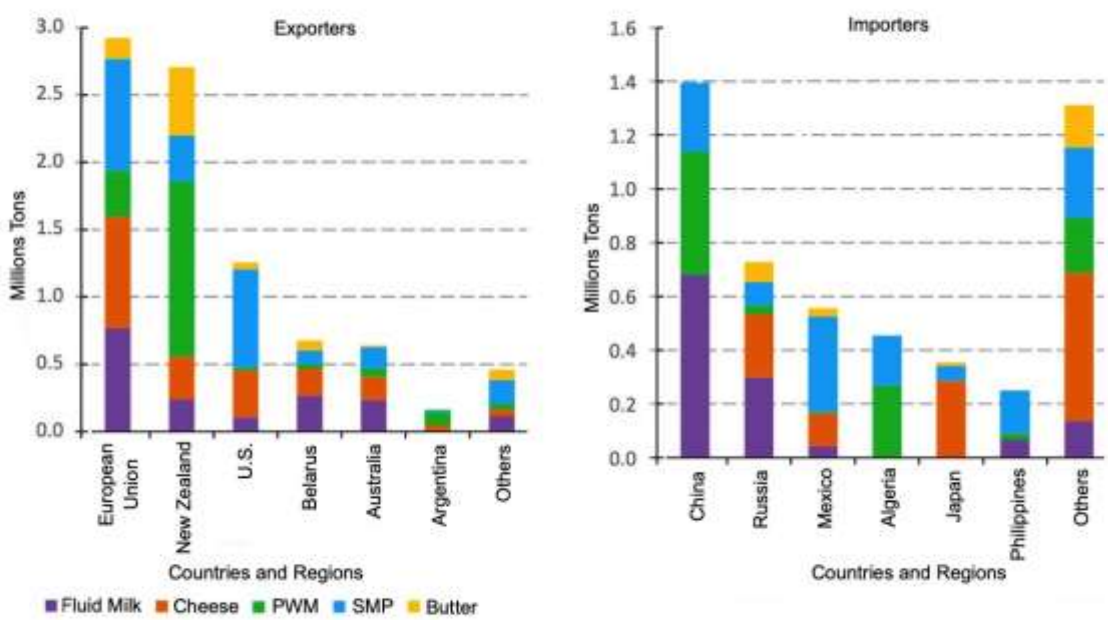


Source of reference: (Fideicomisos Instituidos en Relación con la Agricultura, 2019)

The European Union is the number one largest producer of dairy products, with cheese as its main product, accounting for 67.5% of its total volume (Domínguez-Salas *et al.*, 2019). Cheese is also the most significant dairy product produced in the U.S., at 75.5% of its total volume (United States Department of Agriculture, 2021). Meanwhile, international consumption of dairy products at the end of 2019 stood at 37.3 million t, 3.3% higher than in 2018. The products that showed the highest annual growth in global consumption were cheese, with 52.7% of total consumption, followed by butter with 26.5% (Organization for Economic Cooperation and Development, 2020).

In the international dairy derivatives market, 80% of world exports originate in the European Union, New Zealand, and the U.S. (Figure 3.4). Mexican imports in 2018 accounted for 11% of the total volume, making Mexico the third largest importer of dairy derivatives worldwide (Cámara Nacional de Industriales de la Leche, 2021). Additionally, the U.S. supplied Mexico with 99% of its milk powder imports (Fideicomisos Instituidos en Relación con la Agricultura, 2021). For its part, China is the largest importer of dairy derivatives, its demand during 2018 being 1.39 million t (Food and Agriculture Organization of the United Nations, 2021b). It is worth noting that, compared to cereals and meat, the international price of dairy derivatives has presented its highest growth during the last five years (Organization for Economic Cooperation and Development, 2020). Placing PWM and SMP as benchmarks for setting international prices, due to their importance as inputs in the dairy industry (Kutkowska *et al.*, 2020), during 2020 in Northern Europe (Table 3.3), the minimum price of PWM was 3,300 USD/t, and in Oceania during the same year, the minimum price of SMP was 2,925 USD/t (Oficina de Estudios y Políticas Agrarias, 2021).

Figure 3.4 International Trade of Dairy Derivatives, Year 2018, Million Tons



Source of reference: (United States Department of Agriculture, 2021)

Table 3.3. International Prices for Milk Powder During 2018-2020, USD/t

Year	PWM[a]		SMP[b]	
	Northern Europe	Oceania	Northern Europe	Oceania
	USD/t			
2020	3,300	3,200	2,525	2,925
2019	3,375	3,075	2,775	2,800
2018	3,000	2,550	1,700	1,925

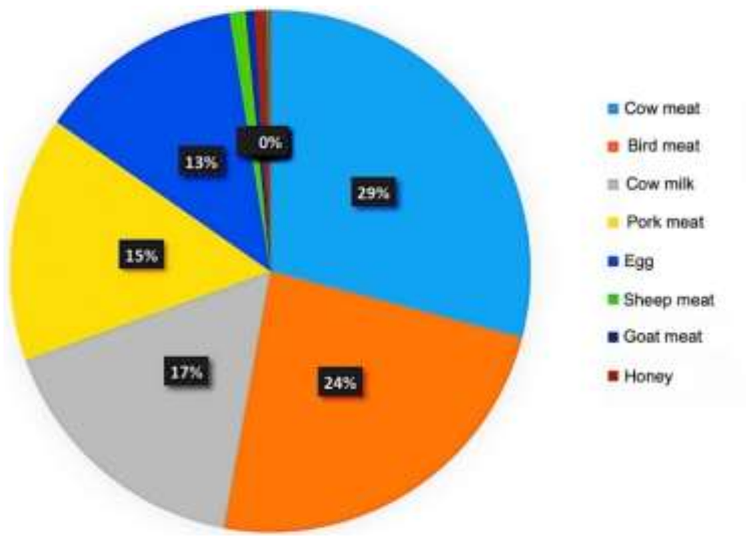
[a] Powdered whole milk. Fat content between 26% and 42%, maximum water content 5%, minimum protein content in lean milk solids 34% (CODEX STAN-207, 1999)
[b]Skim milk powder. Fat content 1.5%, maximum water content 5%, minimum protein content in milk solids-non-fat 34% (CODEX STAN-207, 1999)

Source of reference: (Oficina de Estudios y Políticas Agrarias, 2021)

2. Domestic production and trade of milk and dairy products

In Mexico, milk is defined as the product obtained from the secretion of the cow's mammary gland without colostrum, which must be subjected to thermal treatments or other processes that guarantee its safety. It may also undergo other operations, such as clarification, homogenization, standardization, or others, as long as they do not contaminate the product and comply with the specifications of its denomination (NOM-155 - SCFI, 2003). The Mexican dairy sector is the third most important agricultural activity with 17%, and a contribution of 24% to the Gross Domestic Product (Figure 3.5), behind beef production with 29%, and chicken meat production at 24% (Cámara Nacional de Industriales de la Leche, 2021).

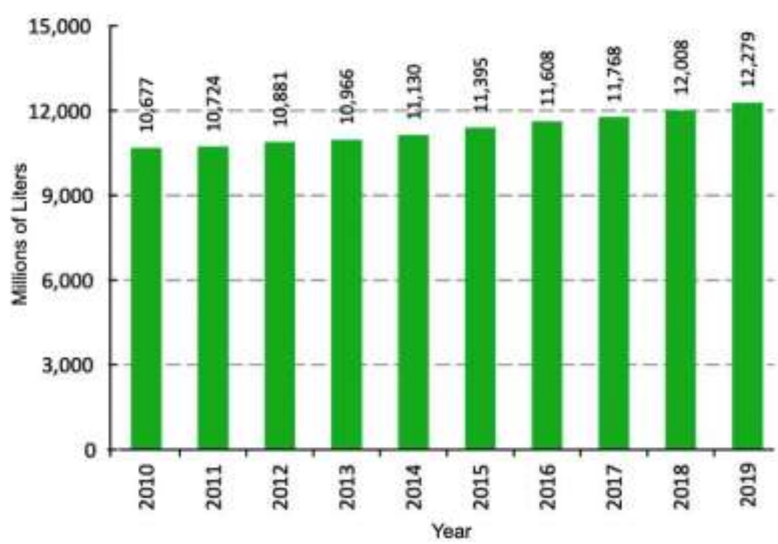
Figure 3.5 Major Agricultural and Livestock Activities in Mexico, Year 2020, Percentages



Source of reference: (Cámara Nacional de Industriales de la Leche, 2021)

According to the Servicio de Información Agroalimentaria y Pesquera (2019), the value of cow's milk production in Mexico, during the period between 2010 and 2019, went from 51 billion pesos to over 79 billion pesos. Moreover, according to data from the Cámara Nacional de Industriales de la Leche (2021), during the same period (Figure 3.6), the production of fluid milk in Mexico grew around an additional 1,331 thousand tons of fluid milk, from 10,677 million liters in 2010 to 12,008 million liters in 2018, representing 16th place in world production of bovine milk.

Figure 3.6 Cow's Milk Production in Mexico, Period 2010-2019, Millions of Liters

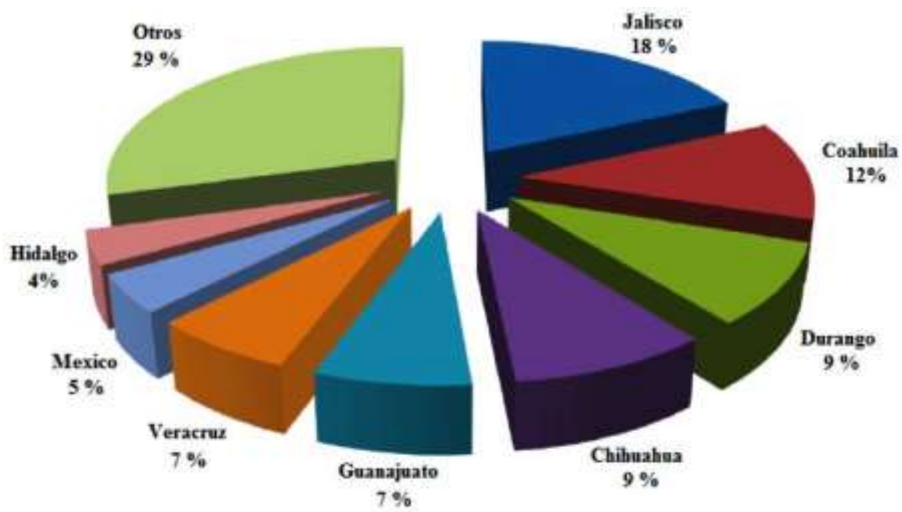


Source of reference: (Cámara Nacional de Industriales de la Leche, 2021)

In Mexico, bovine milk production is higher during the summer (June-September); that is, during the rainy season, when forage availability for cattle feeding is higher (Theusme *et al.*, 2021). It is also heterogeneous from a technological, agroecological, and socioeconomic point of view, including the great variety of climates, reproductive systems, forage quality, and feeding (Food and Agriculture Organization of the United Nations, 2021a). Additionally, the Oficina de Estudios y Políticas Agrarias (2021) indicated that, during 2019, fluid milk production reached 12,279 million liters, with a livestock inventory of 2,563,822 head.

The Confederación Nacional de Organizaciones Ganaderas (2020) indicated that most of the production in 2019 was contributed by 13 states, with Jalisco ranking as the largest producer of cow's milk in Mexico (Figure 3.7), accounting for 2,541,915 thousand liters (equivalent to 18% of the total volume), a livestock inventory of 374,411 heads, and a stocking rate of 8.50 ha/AU/year. This is followed by Coahuila, with 1,394,913 thousand liters (equivalent to 12% of the total volume), a livestock inventory of 244,750 heads, and a stocking rate of 26.02 ha/AU/year.

Figure 3.7 Cow's Milk Production by State, Year 2019, Percentages



Source of reference: (Cámara Nacional de Industriales de la Leche, 2021)

Durango contributed with 1,242,953 thousand liters (equivalent to 9% of the total volume), a livestock inventory of 303,001 head, and a stocking rate of 15.70 ha/AU/year (Confederación Nacional de Organizaciones Ganaderas, 2020). Chihuahua produced 1,160,432 thousand liters, with a livestock inventory of 294,629 heads, and a stocking rate of 20.07 ha/UA/year (Cámara Nacional de Industriales de la Leche, 2021). The rest of the production for 2019 was covered by the states of Guanajuato, Veracruz, State of Mexico, Hidalgo, Aguascalientes, Puebla, Chiapas, Michoacán, and Querétaro (Servicio de Información Agroalimentaria y Pesquera, 2019).

At this point, it is appropriate to mention that the main municipalities that combined for just over 29% of national production were: i) Gómez Palacio, Durango (6.9%); ii) Matamoros, Coahuila (4.6%); iii) Delicias, Chihuahua (3.5%); iv) Francisco I. Madero, Coahuila (3.0%); v) Encarnación de Díaz, Jalisco (2.3%); vi) Torreón, Coahuila (1.9%); vii) San Miguel el Alto, Jalisco (1.9%); viii) Tepatitlán de Morelos, Jalisco (1.8%); ix) Lagos de Moreno, Jalisco (1.8%); and x) Tizayuca, Hidalgo (1%) (Confederación Nacional de Organizaciones Ganaderas, 2020).

In Jalisco, Coahuila, Durango, and Chihuahua (Figure 3.8), intensive or specialized production systems prevail, where animals are kept in stalls and their feed is offered at the trough (Reyes and Rosales, 2018). Farming for forage production and milking in the vast majority of the Dairy Production Unit (DPU) with this system are highly mechanized, with average yields/cow of 5,000 L/lactation, with a calving interval between 12 and 13 months, and a lactation period that fluctuates between 210 and 305 d/year (Camacho *et al.*, 2017).

Figure 3.8 Intensive or Specialized Production System – Delicias, Chihuahua

Source of reference: Personal photo

In Guanajuato, State of Mexico (Figure 3.9), Hidalgo, Aguascalientes, Puebla, Michoacán, and Querétaro, with stocking rates of 10.20, 9.33, 6.41, 11.56, 7.82, 7.00, and 13.49 ha/AU/year respectively, semi-intensive or semi-specialized production systems prevail, where cattle are kept in semi- stabulation during the hottest hours of the day, going out to graze in the cooler hours of the afternoon (Camacho *et al.*, 2017). In most of the stabulation system, feeding is variable, as it depends on agricultural production complemented with cut forages and concentrates, with average yields/cow of 2,500 L/lactation, and a calving interval close to 16 months (Fideicomisos Instituidos en Relación con la Agricultura, 2021).

Figure 3.9 Semi-Intensive or Semi-Specialized Production System – Texcoco, State of Mexico

Source of reference: Personal photo

As for Veracruz and Chiapas, with stocking rates of 1.81 and 1.80 ha/AU/year respectively, dual-purpose cattle ranching predominates, with average yields/cow of 800 L/lactation, weaning calves at 8 to 10 months of age with 156 kg of LW, and a calving interval between 17 and 20 months (Albarrán *et al.*, 2015). Dual purpose cattle ranching (Figure 3.10) has Simmental, Brahman, and crosses of specialized European or Creole *Bos taurus* (BT) breeds with *Bos indicus* (BI) breeds, in order to increase productive potential through the inclusion of BT genes, while BI genes will give the new genotype adaptations to tropical conditions (Reyes and Rosales, 2018).

Figure 3.10 Dual Purpose Production System – Tlapacoyan, Veracruz

Source of reference: Personal photo

Regarding the climatic conditions for cow milk production in the 196,717,300 ha of the national territory, the Secretaría de Medio Ambiente y Recursos Naturales (2021) has established a typology that considers its distribution by agro-ecological-livestock regions (Table 3.4).

Table 3.4 Agro-Ecological-Livestock Farming Regions for Cow's Milk Production in Mexico

Region	States
Arid and Semi-Arid 94,992,673 ha	Baja California Norte y Sur, Coahuila, Chihuahua, Durango, Nuevo León, San Luis Potosí, Sinaloa, Sonora, Tamaulipas, and Zacatecas
Temperate 46,036,751 ha	Aguascalientes, Guanajuato, Hidalgo, Jalisco, State of Mexico, Michoacán, Morelos, Puebla, Querétaro, Tlaxcala, and Mexico City
Humid and Dry Tropical 55,687,876 ha	Campeche, Colima, Chiapas, Guerrero, Nayarit, Oaxaca, Quintana Roo, Tabasco, Veracruz, and Yucatán

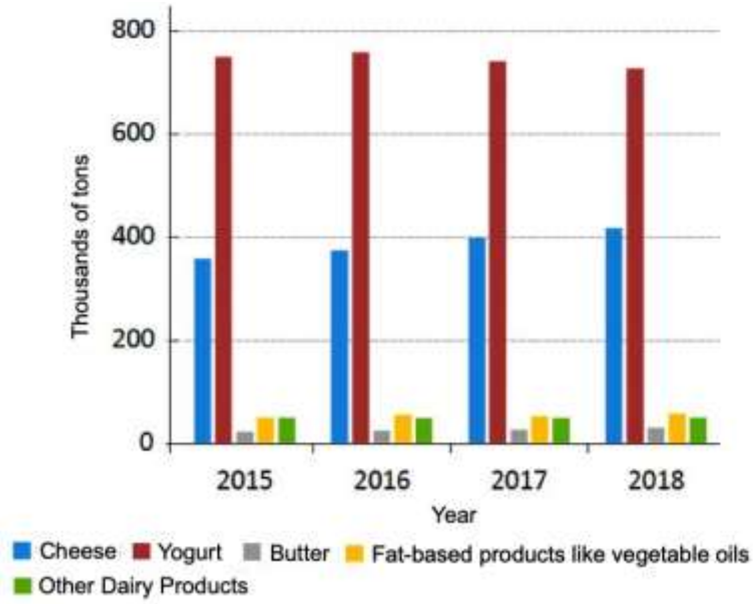
Source of reference: (Secretaría de Medio Ambiente y Recursos Naturales, 2021)

Due to its importance in the national milk supply, the Cámara Nacional de Industriales de la Leche (2021) highlighted the Comarca Lagunera in the arid and semi-arid agro-ecological-livestock region, formed by 16 municipalities: 5 in Coahuila, and 11 in Durango and Chihuahua, including its links with milk companies (e.g., Grupo Lala^{MR}).

In the temperate agro-ecological-livestock region, the work is carried out by the municipalities of Texcoco, Zumpango, Teoloyucan, Jilotepec, Aculco, Polotitlán, Tequixquiac, and Acolman, all in the State of Mexico, and their links with milk collection companies, such as Nestlé^{MR}, stood out. This is further enabled by the Tizayuca Agricultural and Industrial Complex in Hidalgo State, and its links with milk collecting companies (e.g., Ganaderos Productores de Leche Pura-Alpura^{MR} and Santa Clara^{MR}).

Even though the region with the greatest availability of water in the country is the humid tropics, it should be noted that its climatic conditions have apparently not been the determining factors in the productivity of its states, since Coahuila and Durango, located in the arid and semi-arid region of the country, are in second and third place in production (Confederación Nacional de Organizaciones Ganaderas, 2020). Regarding the processing of dairy derivatives, during 2018, 1.42 million t were produced, with a total value of 52,262 million pesos (Fideicomisos Instituidos en Relación con la Agricultura, 2021). Yogurt is the most produced dairy derivative in Mexico (Figure 3.11), representing 43.6% of the total volume. 29.6% corresponded to cheese, and 16.9% to powdered milk, with the remaining 9.9% attributed to butter and other products (Instituto Nacional de Estadística y Geografía, 2021).

Figure 3.11 Production of Dairy Products During 2015-2018, Thousands of Tons



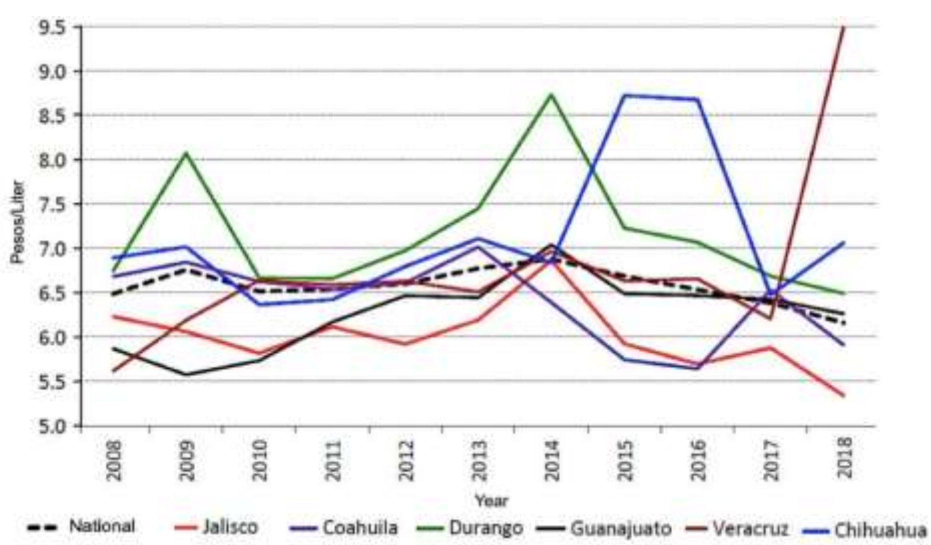
Source of reference: (Instituto Nacional de Estadística y Geografía, 2021)

In the national trade of milk and dairy products, Mexico ranks 8th in milk consumption worldwide (Servicio de Información Agroalimentaria y Pesquera, 2019). During 2018, apparent national consumption stood at 15,288 million L; only 78.5% of that volume was supplied from the 12,008 million L produced nationally (Confederación Nacional de Organizaciones Ganaderas, 2020), being insufficient to meet the total demand of the population. The remaining 21.5% was supplied by imports, mainly powdered milk from the U.S. (United States Department of Agriculture, 2021).

For its part, the Consejo Nacional de Población (2018) indicated that the annual *per capita* consumption of milk was 122 L; cheese consumption was 4.3 kg; powdered milk consumption was 3.6 kg; and butter consumption was 2 kg – values below *per capita* consumption in developed countries (e.g., the European Union and the U.S.).

The Federal Government implemented the Guarantee Price Program for Basic Food Products, which included milk (Confederación Nacional de Organizaciones Ganaderas, 2020). Due to this program, Liconsa purchases milk mainly from producers with a livestock inventory of up to 100 head, setting the base price at 6.2 $/L during 2018 (Figure 3.12). It also specifies bonuses (Table 3.5) according to the lipid and protein concentration of the milk, and its bacteriological quality (Liconsa, 2019).

Figure 3.12 Price per Liter of Fluid Milk in Mexico, 2008-2018, Pesos/Liter



Source of reference: (Fideicomisos Instituidos en Relación con la Agricultura, 2019)

Table 3.5 Economic Stimulus per Liter of Fluid Milk in Mexico, Pesos/Liter

Stimulus				$/L
Quality	Physicochemistry	Fat	3.00 to 3.29 g/100 mL	0.05
			3.30 to 3.39 g/100 mL	0.10
			≥ 3.40 g/100 mL	0.20
		Protein	3.00 to 3.09 g/100 mL	0.05
			≥ 3.10 g/100 mL	0.10
	Bacteriological	Somatic Cells (SC)*	Class 3: 501,000 to 749,000 SCC/mL	0.05
			Class 2: 401,000 to 500,000 SCC/mL	0.10
			Class 1: ≤ 400,000 SC/mL	0.15
		Reductase	120 to 179 min	0.05
			180 min or more	0.10
		Antibiotic	Negative	0.05
* Specifications on somatic cell content in raw milk (NMX-F-700-COFOCALEC, 2012)				

Source of reference: (Liconsa, 2019)

3. Productive and reproductive parameters of dairy cattle

Identifying the parameters of the cattle herd is of vital importance, since they are zootechnical indicators that indicate whether the animals are expressing their productive and reproductive potential (Recinos *et al.*, 2017). If this is not achieved, the producer must carry out specific strategies in nutrient balance, animal and paddock management, sanitation, etc., all based on the productivity biotype (Table 3.6) of his/her cattle (De-la-Barra *et al.,* 2019), ultimately understanding this as the correlation between the external conformation (rectangular parallelepiped), with its aptitude for meat production (triangular angular), and with its aptitude for milk production and/or their combinations (Bewley *et al.*, 2017).

Table 3.6 Main Characteristics of Bovine Biotypes Used in Mexico

	Birth Weight (kg)	Daily Weight Gain (d/kg)	LWF[1] (kg)	Carcass Yield[2] (%)
Angus	28.0	1.17	482	59.1
Brahman	40.4	1.13	499	62.1
Brangus	35.1	1.13	485	60.9
Beefmaster	37.4	1.19	504	61.7
Charolais	39.2	1.25	527	61.0
Brown Suiss	37.5	1.18	504	60.6
Holstein	35.0	1.24	521	60.5
Simmental	38.6	1.17	495	59.1
[1]Final weight of the animal at the end of its life; [2] Final weight of the carcass of cattle slaughtered at the slaughterhouse, from which the head, skin, viscera, and carcasses have been removed				

Source of reference: (Boichard et al., 2015)

Similarly, it is important to identify the stocking rate, or average number of animal unit (**AU**) equivalent to a 450 kg LW bovine (Table 3.7), which are assigned to an area for a given grazing period (Benevenute *et al*., 2020), the carrying capacity or degree of forage production, which allows the pasture plants to recover after said grazing period (Vásquez *et al.*, 2019), and the stocking rate, or area necessary to sustain one AU/year permanently and without deteriorating natural resources (Alcalá-Galván *et al.*, 2018).

Table 3.7 Type of Animal and Its Equivalents in Animal Unit, Calculated Based on Metabolic Weight

Type of Animal (average in kg)	Animal Unit Equivalents on a Liveweight Basis
Weaned animal < 360	0.75
Young animal between 360 and 400	0.85
Cow between 400 and 500	1.00
Cow between 500 and 600	1.15
Cow > 600	1.25
Bull < 900	1.50
Bull > 900	2.00

Source of reference: (Buchanan and Lenstra, 2015)

Milk production in different regions of the world develops independently. However, the development and adoption of a series of production parameters (Table 3.8) allowed a significant increase in milk production (Callejas *et al.,* 2017; Camacho *et al.,* 2017). At the same time, other scientific advances related to the identification and use of physiological constants (Table 3.9) were incorporated in order to maintain metabolic checkpoints in herd health (Hoffmann *et al.,* 2019).

Table 3.8 Dairy Cattle Production Parameters

Size	Birth	Suckling	Weaning	Puberty	Breeding (natural or AI*)	First Calving (24 months)
Big[a]	35 kg of LW†	3 months	70 to 100 kg of and a concentrate consumption of 650 to 750 g/d	6 to 10 months with 300 kg of LW	12 to 14 months with 350 kg of LW	550 kg of LW
Median[b]	25 kg of LW					450 kg of LW
	1st Lactation	Dry Period	End of 1st Lactation (2nd calving)		End of 2nd Lactation (3rd calving)	
Big[a]	305 d	60 d	650 kg of LW		750 to 800 kg of LW	
Median[b]			550 kg of LW		650 kg of LW	
CC+	Puberty	Breeding	Calving	Peak Production	2nd Third of Lactation	Dry Period
	2.5	2.5	3.5	2.7	3.0	3.5
[a]Holstein; [b]Jersey; *Artificial Insemination at Fixed Time; +Body Condition; †Liveweight						

Source of reference: (Camacho et al., 2017; Rivera et al., 2016)

During milk production, many metabolic and endocrine adaptations occur that, if ignored, will have a negative economic impact on the DPU (Castellón, 2015) by increasing the incidence of pathologies during the transition and postpartum period, and increasing the calving interval, due to an inadequate return to estrus (Britt *et al.,* 2018; García *et al.*, 2020).

Table 3.9 Physiological Constants in Cattle

Physiological Stage	Temperature (°C)	Heart Rate (mov/min)[1]		Respiratory Rate (rep/min)[2]	Ruminal Movements (mov/2 min)[3]	
Adult	37.7 - 38.5	40 - 80		10 – 30	2 - 3	
Young	38.5 - 39.5	80 - 110		15 – 40		
	Milk	Urine	Blood	Ruminal Liquid	Abomasal Fluid	Saliva
pH[a]	6.5 -7.0	7.4 - 8.4	7.3 - 7.4	5.5 - 7.0	2.0 - 3.0	7.9 - 8.5
[1]Movements per minute; [2]Repetitions per minute; [3]Movements per two minutes; [a]Potential of hydrogen						

Source of reference: (Hoffmann et al., 2019)

This is so much so that researchers and specialists in dairy cow reproduction recognize the importance of reproductive parameters (Table 3.10), in order to: i) Ensure the correct development of the feto-placental unit (García *et al.,* 2019); ii) Maintain an appropriate body condition (Mulligan and Doherty, 2008); iii) Prepare the mammary gland for the next lactation (Bruckmaier and Gross, 2017); and iv) Optimize milk production (Goff, 2006).

Table 3.10 Reproductive Parameters of Dairy Cattle

Physiological Event	Duration
Lactation	305 d (10 months)
Interval between births	Between 12 and 13 months
Age at first calving	24 months (2 year of life)
Days open	85 to 100 d (3 months)
Services per conception	1.0 to 1.65
First lactation	Between 2nd and 3rd year of life
Gestation	9 months: 2 embryonic development and 7 fetal development
Embryo implantation	35 d
Peak milk production	From the 6th to the 8th week postpartum
Dry period	60 d (2 months)
Percentage of fetal mortality	< 5 %
Metestrus	2 d
Diestrus	15 d
Proestrus	3 d
Estrus	18 to 24 h
Puerperium	30 to 50 d

Source of reference: (Davidson and Stabenfeldt, 2014b; Fails and Magee, 2018)

In general, these metabolic and endocrine adaptations reflect physiological changes that occur to facilitate the process of parturition (Davidson and Stabenfeldt, 2014a), prepare the mammary gland for colostrum and milk synthesis (García *et al*., 2020), and develop folliculogenesis to achieve a new conception (Jaffe and Egbert, 2017).

4. Good feeding practices in dairy cattle

Animal nutrition is the branch of zootechnics that deals with the distribution of food, with the objective of replenishing the cellular losses incurred by the activity of the organism (Weiss and Tebbe, 2018). Transforming the energy contained in food into heat, movement, work, and production (Galyean *et al.,* 2016), the balance of nutrients in the DPU significantly impacts milk production and the concentration of milk solids (e.g., protein) (Tedeschi *et al.,* 2017).

Those strategies that optimize rumen function use the classification of ruminant feeds, indicated by the National Research Council (2001), which distinguish three main groups of feeds: i) Energy feeders or feeds containing large amount of usable energy/unit weight (e.g., feed grains, molasses, fats and oils, brewery by-products, roots and tubers, beet and citrus pulp, bakery wastes, and oleins) (Parihar *et al.,* 2018); ii) Protein feedstuffs or feeds containing more than 20% of their weight as crude protein (**CP**) (e.g., meals of animal origin, protein of single cell origin or single cell protein, and non-protein nitrogen (**NPN**)) (Mulligan and Doherty, 2008); and iii) Fibrous feedstuffs or feeds containing high crude fiber content (e.g., dry hay or haylage, straw or stubble, and wet silage) (Jardstedt *et al.,* 2018).

In dairy cows, the transition period (21 d before and 21 d after calving) is the most critical physiological stage in milk production (García *et al*., 2020). During this time, significant amounts of energy inputs are incorporated into the diet (Reddy *et al.,* 2008). When this happens suddenly, the amylolytic bacterial flora is increased, and a high amount of lactic acid is produced (Kraut and Madias, 2010). In the rumen, lactic acid-consuming bacteria metabolize lactic acid to acetic, propionic, and butyric acid (Calsamiglia *et al*., 2008). However, the development of these bacteria is slow, resulting in delayed development of ruminal papillae, as they are primarily dependent on the presence of propionic (Aschenbach *et al.,* 2019), compromising nutrient supply to the mammary gland, and negatively impacting milk production (Tedeschi *et al.,* 2017).

Therefore, proper nutritional management practices are necessary, including: i) Maintaining the average hay [cut material, with 15% moisture and 85% dry matter (**DM**)] that requires an AU/d close to 3% of its LW (Figure 3.13), equivalent to 13 kg DM/d (National Research Council, 2001); ii) Maintaining the average silage (cut and fermented material with 60% moisture and 40% DM) that requires an AU/d close to 2% of its LW, equivalent to 9 kg DM/d (Jardstedt *et al.,* 2018); iii) Maintain the forage/concentrate ratio required to stabilize milk fat percentage, close to 40% forage and 60% concentrate (Bewley *et al.,* 2017); iv) Conserve average straw or stubble (remains of grass stalks, such as wheat and oats left on the ground after cutting the crop), which requires an AU/d close to 1% of its LW, equivalent to 4.5 kg DM/d (National Research Council, 2001);

Figure 3.13 Corn Silage (*Zea mays*) and Alfalfa Hay (*Medicago sativa*)

Source of reference: Personal photo

v) Employ yeast cultures to stabilize the rumen environment and improve fiber digestion (Dias *et al.*, 2018); vi) Maintain the average water required by an AU/d close to 10% of its LW, equivalent to 45 L divided in four periods, (plus 5 L/L of milk, if in production) (Bewley *et al.*, 2017); and vii) Use ionophores (e.g., monensin produced by a *Streptomyces cinnamonensis* strain) to inhibit the growth of $Gram^+$ bacteria in the rumen, enhance carbohydrate fermentation, increase propionic acid production (Kozerski *et al.*, 2017), and decrease methane (**CH_4**) production by -12 ± 6 g/d in dairy cows and -14 ± 6 g/d in beef cattle (Appuhamy *et al.*, 2013). These recommendations are only a practical guide, as there are other factors that also impact dairy cattle nutrition, such as rumen pH, and the type and physical form of dietary ingredients (Bewley *et al.*, 2017).

5. Best management practices for dairy animal facilities

For the establishment of a DPU, it should be in places where there is no interference with areas exposed to physical, chemical, and microbiological contamination (e.g., landfills, wastewater canals, industrial and urban areas), in order to minimize the introduction of hazards that affect safety during milk production (Gasque, 2008). The facilities should allow for daily activities (e.g., movement of cattle), considering their zoometry (Table 3.11) and social space, cleaning of infrastructure, and supply of incoming and outgoing inputs (Hernández *et al.*, 2017).

Table 3.11 Zoometry of Cattle, Social Space

Age	Length (cm)	Width (cm)	Height at Withers (cm)
	Calves		
14 days	118	25	81
3 months	132	32	89
6 months	173	44	107
1 year	210	59	125
2 years	220	63	131
	Cows		
600 kg of LW*	230	65	138
700 kg of LW*	240	70	144
*Liveweight			

Source of reference: (Hernández et al., 2017)

Housing, aisles, corrals, floors, and drainage must provide a healthy and comfortable environment for cattle, safeguarding their five freedoms of animal welfare: i) Freedom from hunger and thirst; ii) Freedom from fear and distress; iii) Freedom from pain, injury, or pathology; iv) Freedom from discomfort; and v) Freedom to express animal behavior (Kelly and Ryan, 2016). It should also facilitate favorable conditions for operators, and be integrated into the sub-systems of feeding, milking, and manure management (Secretaria de Agricultura Ganadería Pesca y Alimentación, 2014). The dimensions of the pens should adapt to the given number of cows, their production levels, age, and need for replacement (Gasque, 2008). To determine these dimensions, it is necessary to know the recommended area/cow, and the recommended space for housing (Servicio Nacional de Sanidad Inocuidad y Calidad Agroalimentaria, 2020):

- Area for dry weather pen: 12 to 12.5 m^2/cow;
- Area for wet weather pen: 12 to 20 m^2/cow;
- Space for earthen pen: 45 to 55 m^2/cow;
- Individual free-access cubicle space for paved pen: 9 m^2/cow; and
- Individual free-access cubicle space for dirt pen: 31 m^2/cow.

The shade orientation should be from north to south, with a variation of 11º and 5% slope, especially in climates with defined and abundant rainy seasons (Figure 3.14), with a minimum height of 3 m above ground level (Hoffmann *et al.*, 2019). To determine the shaded area, it is necessary to know the characteristics of the animals (Secretaria de Agricultura Ganadería Pesca y Alimentación, 2014).

- Shaded area for animals with 400 to 600 kg LW: 2.5 to 3.0 m^2/cow;
- Shaded area for steers with 300 to 400 kg LW: 2.0 to 2.5 m^2/head; and

– Shaded area for steers < 300 kg LW: 1.8 to 2.0 m^2/head.

Figure 3.14 Shades for Climates with Defined and Abundant Rainy Seasons, Paved Pens

Source of reference: Personal photo

Each feeder should have a 1.8 to 2.4 cm sidewalk towards the inside of the pen, to avoid floor wear and waterlogging (Gasque, 2008). The size of the trough should be adjusted to the number of animals housed in the pen, and the linear space/animal (Figure 3.15) should be proportional to their LW (Servicio Nacional de Sanidad Inocuidad y Calidad Agroalimentaria, 2020):

– Linear trough spacing for animals with < 270 kg LW: 45 to 55 cm/head;
– Linear trough spacing for animals with 270 to 350 kg LW: 55 to 66 cm/head;
– Linear trough spacing for animals with > 350 kg LW: 60 to 75 cm/head; and
– Linear feeding space for adult cows: 67 to 76 cm/cow.

Figure 3.15 Linear Feeding Trough Space for Dairy Cattle

Source of reference: Personal photo

Adult cattle require, on average, 45 L of water/d, divided into four periods (plus 5 L/L of milk, if in production) (Bewley *et al.*, 2017). Therefore, a 1 m linear trough can supply 25 AU/year, if a daily supply of 1,125 L is guaranteed (Kelly and Ryan, 2016). Consider 3 to 6 linear cm/animal (Figure 3.16), excluding the float and a height of 40 to 50 cm (Donworth, 2016).

Figure 3.16 Drinking Troughs in Paved Pens for Dairy Cattle

Source of reference: Personal photo

Silos are either trench-type (excavated) or bunker-type (above ground). Their capacity is adjusted to the programmed forage diet and, on average, require 2.1 m^3/t of stored forage (Servicio Nacional de Sanidad Inocuidad y Calidad Agroalimentaria, 2020). Haylofts (Figure 3.17) are sheds which are open on all sides or have a flat roof and, on average, require 5.44 m^3/t of stored forage in bales (Kelly and Ryan, 2016).

Figure 3.17 Hayloft for Storing Fodder in Bales

Source of reference: Personal photo

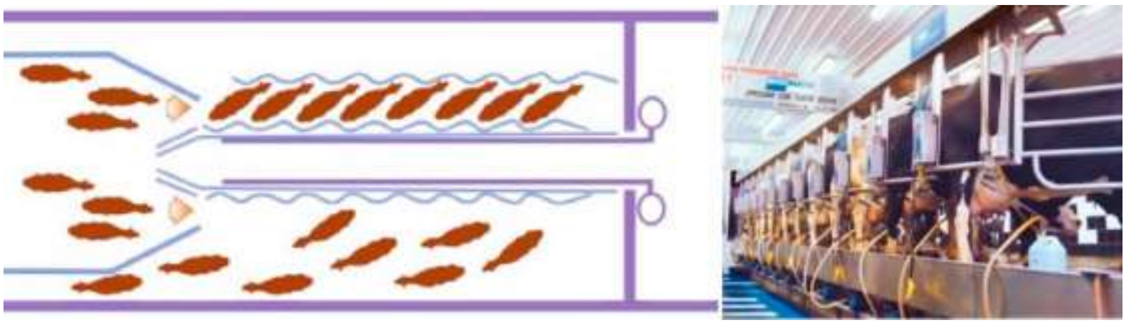
The DPU should have a calf hutch, outdoor or portable calf hutches (Figure 3.18), and individual pens with a covered and uncovered area (Donworth, 2016). Furthermore, there should be calving areas with individual cubicles that are well-protected and ventilated, with good drainage and adequate space (16 m2/cow), including individual feed and water troughs (Gasque, 2008).

Figure 3.18 Calf Hutch and Portable Calf Hutches

Source of reference: Personal photo

This should be specified according to herd size, DPU technification, type of cattle, available land and labor, five main milking parlors, and equipment used in the national territory: i) Herringbone, ii) Tandem, iii) Conventional stall, iv) Parallel, and v) Rotary or carousel (Bokusheva and Čechura, 2017). The herringbone parlor consists of two levels: On the first level, cows are accommodated in an oblique position, with 35° in relation to the longitudinal axis of the parlor (Figure 3.19), with the tail of the animals facing the milkers' aisle (Britt *et al.,* 2018); the second level is a pit with a depth of 75 to 80 cm, for the transit and handling of the milkers (Donworth, 2016). This type of milking parlor usually has feeding troughs for the supply of concentrate (Camacho *et al.,* 2017).

Figure 3.19 Herringbone Milking Parlor



Source of reference: Personal illustration and photo

The tandem parlor, like the herringbone parlor, is a double-level parlor (Kelly and Ryan, 2016). Cows are handled individually, being immobilized in cages that are placed one behind the other in a linear fashion, with one entrance and one exit door (Gasque, 2008). The conventional stall room is a single row of stalls with only one level (Kelly and Ryan, 2016). Cows are placed parallel to each other and are immobilized by individual or collective adjustment chains (Servicio Nacional de Sanidad Inocuidad y Calidad Agroalimentaria, 2020).

The parallel parlor (Figure 3.20) has two levels: An aisle for the cows and a pit for the milkers (Gasque, 2008). The animals are handled in groups; they are perpendicular to the pit, and their exit is from the front (Secretaria de Agricultura Ganadería Pesca y Alimentación, 2014).

Figure 3.20 Parallel Milking Parlor

Source of reference: Personal illustration and photo

The rotary parlor or carousel is used to milk a high number of cows in a short time frame (Gasque, 2008). The animals are arranged on mobile platforms that can be individual or collective (Kelly and Ryan, 2016). In this milking system, cows are managed in groups, seeking to maximize the total yield of the facility (Servicio Nacional de Sanidad Inocuidad y Calidad Agroalimentaria, 2020). In all DPU, handling pens are necessary (Figure 3.21), equipped with chutes to allow proper flow of cows from one location to another (e.g., landing area to handling area, or to receiving pens with scales) (Donworth, 2016).

Figure 3.21 Handling Pens Equipped with Squeeze Chute

Source of reference: Personal photos

Finally, manure is a waste that favors the proliferation of potentially pathogenic microorganisms in the pens (Bewley *et al.,* 2017). In high concentrations, it releases ammonia (NH_3) into the environment (Rodwell, 2018), and in concrete pens, it causes slips, injuries, or infections in the feet (Rodríguez *et al.,* 2015). Therefore, if manure management is ideally structured, an area should be available for its deposition (pit with discharge chute), with adequate capacity for the rate of evacuation or use of manure by the DPU (Servicio Nacional de Sanidad Inocuidad y Calidad Agroalimentaria, 2020).

Conclusions

Between 2008 and 2018, global bovine milk production grew at an annual rate of 1.4%. The production of dairy derivatives (e.g., cheese, butter, and powdered milk, both skim and whole) continues to grow. In Mexico, cow's milk production grew at an annual rate of 2% to an all-time high of 12,279 million L during 2019. Although milk production continues to grow, it has not been sufficient to meet the requirements of the domestic market, revealing productivity gaps in Mexican Dairy Production Units. These productivity gaps reflect the integral management of livestock enterprises, considering nutrition, reproduction, facilities, animal welfare, and other zootechnical management practices.

However, the heterogeneity of the different cow milk production systems in Mexico gives rise to particular problems of productivity, competitiveness, and sustainability, all with their own associated characteristics, regions, and management. Therefore, this paper examines and integrates the international and national milk market, and the main zootechnical and economic indicators of its production, as a viable and practical proposal that allows cattlemen to participate successfully in national production in a globalized market where economies with unequal conditions are confronted. This information will serve as a support for anyone involved in, or related to, the sustainable production of dairy cows.

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